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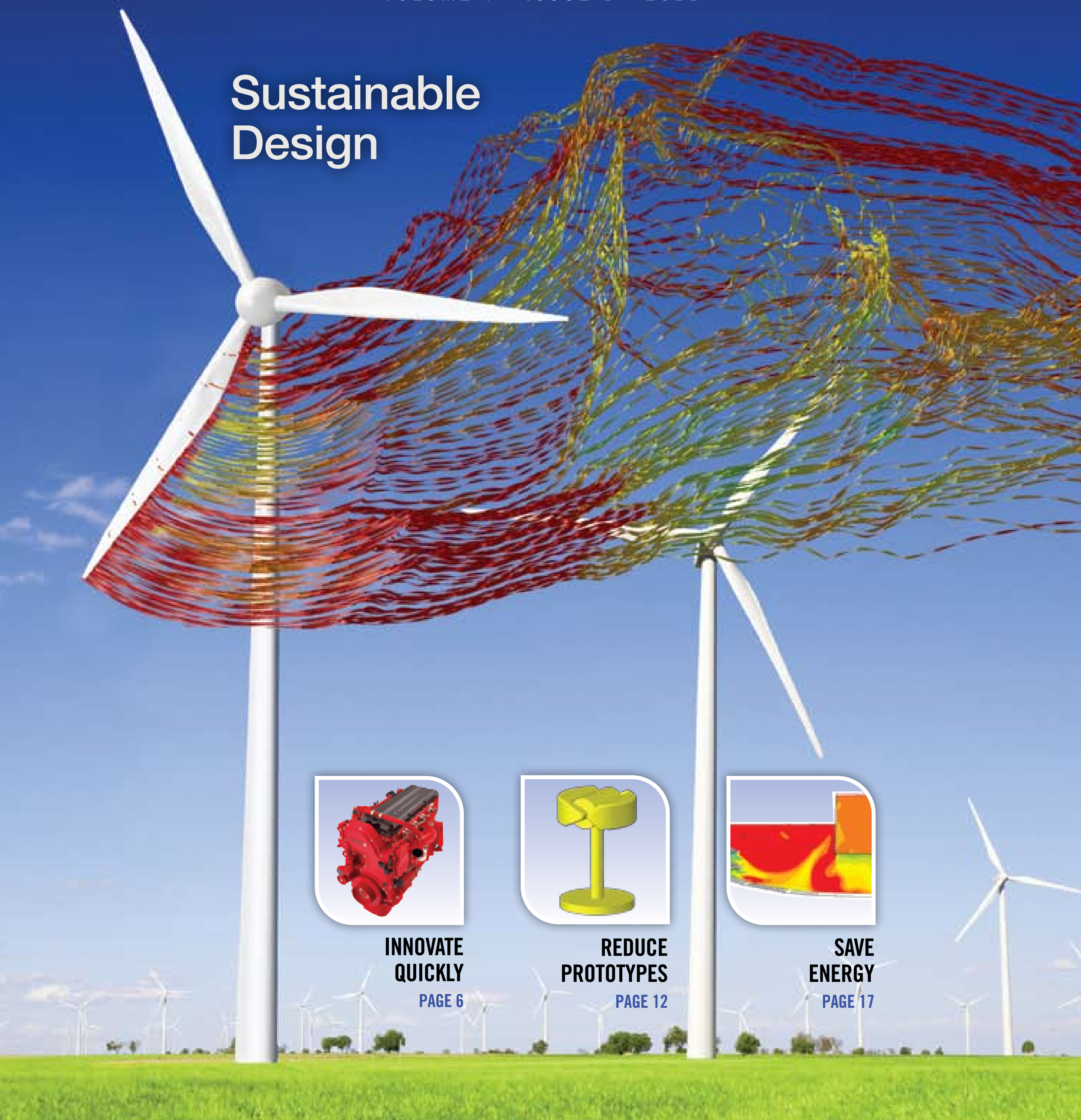
VOLUME V ISSUE 1 2011



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Second Wind

Advanced turbulence models lead to optimized wind turbine spacing.

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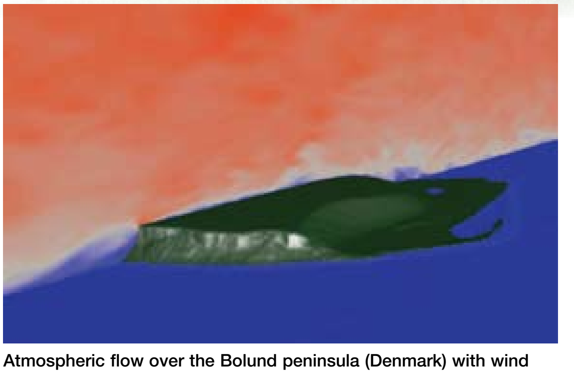
With the Global Wind Energy Council projecting that wind power installations will grow to 409 gigawatts in 2014, the amount of land occupied by wind farms is becoming a serious concern. The issue is already critical in Germany because of dense population and the country's leadership in deploying wind power. Typically the goal is to generate as much power as possible at the lowest cost from a given wind farm site. But there are drawbacks to spacing wind turbines too close together, including lower power output and wake effects.

Fluid & Energy Engineering (F2E) GmbH & Co. KG is pioneering the use of advanced turbulence models such as large eddy simulation (LES) to increase the accuracy with which turbines can be sited within a wind farm. The end result will be the ability to generate more energy from a given volume of land.

The wake of a turbine has significant effects — including reduced power output and shorter turbine life — on any turbine in its path. Extracting energy from incoming wind causes a loss in the kinetic energy and velocity of the wind in the wake of a turbine. This energy is recovered over distance as the wake exchanges energy with the surrounding wind. Turbulence produced in the wake of turbines and turbulence produced by terrain features such as forests or hills can have a substantial impact on turbine life. The effects of turbulence can vary with the flow angle and inclination of the incoming wind. For example, one of the most damaging scenarios is when one half of a rotor experiences turbulence from an upwind turbine and the other half is exposed to undisturbed flow.



Atmospheric flow over the Bolund peninsula (Denmark) with wind direction from the escarpment on the west side. The red color indicates high wind speeds, and blue indicates low speeds.

Wind field behind an ENERCON E-66 wind turbine with hub height of 65 meters. The blue color indicates high wind speeds, and white indicates low speeds.

Meandering wake behind an ENERCON E-66 wind turbine. Blue represents high wind speed, and white represents low speed.

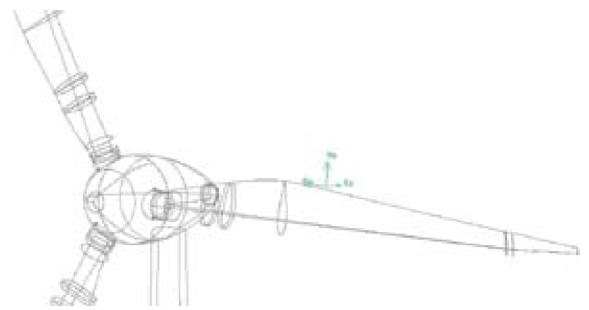
In Germany, loan organizations and regulatory authorities require an assessment of every new wind farm project to ensure that turbulence loads generated by terrain and wind turbine wakes are within acceptable design limits. Terrain and wind turbine wakes must be considered together because they have additive effects on turbulence. Typically, the approach to computing these loads is to use standard empirical formulas to estimate terrain-generated and wake-generated turbulence intensity and to use blade momentum theory to estimate the loading on the blades.

However, the accuracy of these empirical calculations can be limited because they do not incorporate the actual geometry of the rotors and terrain. The result is that the calculations need to be heavily calibrated to produce safe wind farm designs. These empirical models show that wind turbines typically must be spaced at a distance of about four rotor diameters from each other. Required spacing can be even greater if terrain-generated turbulence is a major factor.

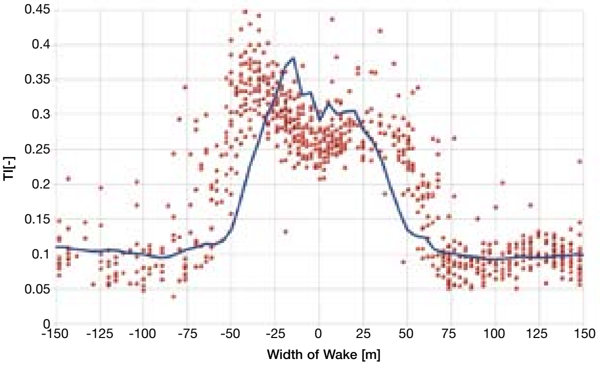
Developers of wind farms are demanding more accurate methods for calculating the turbulence intensity generated by wakes and terrains so that they can produce more energy from a given parcel of land. F2E has been using computational fluid dynamics (CFD) over the last decade to address this important issue. The company's engineers generally have had little difficulty in determining the wind velocity in the wake of a turbine, but calculating the turbulence intensity is much more challenging.

Conventional Reynolds-averaged Navier–Stokes (RANS) models reduce the computational time required to simulate turbulent flows by time-averaging the velocity field, pressure, density and temperature over time. This approach eliminates turbulence fluctuations and makes it possible to model turbulent flow in a reasonable time on desktop computers. RANS methods are effective at predicting the overall and steady-state behavior of a wind farm; however, their accuracy suffers in modeling unsteady turbulent flows that are typically found in wind farms.

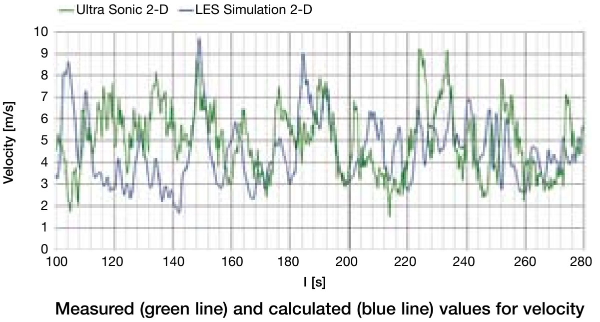
Over the past three years, F2E has used the LES turbulence model with very positive results. It numerically resolves the larger turbulence scales and models the smaller scales to provide accurate transient solutions of the flowfield. Most recently, F2E engineers used ANSYS FLUENT software to model the full geometry of two ENERCON E-66 wind turbines with 66 meter rotors using the LES technique. The fluid dynamics results were validated with data collected in an actual wind farm using ultrasonic anemometers. Fluid dynamics accurately predicted the velocity of the incoming wind along with turbulence intensity at the downwind turbine over the width of the wake.



Model of a wind turbine used for computational fluid dynamics simulation



Simulation of local turbulence intensity (blue line) compared to measurements (red dots) across width of wake



Measured (green line) and calculated (blue line) values for velocity magnitude at hub height in center of wake over 180 seconds

Fluid dynamics did a good job of predicting the variation in the velocity over a period of 300 seconds, a figure that can be used to calculate turbulence intensity and the aerodynamic loads that turbulence creates. Quick horizontal shifts of the wake from one side to another are detectable on a 25 second time scale. Another critical factor in achieving this level of accuracy was the accurate modeling of the incoming wind field and, particularly, the variation in its wind direction and the wind shear.

Fluid dynamics and LES techniques from ANSYS can be used to calibrate and greatly improve the accuracy of empirical calculations that are currently used to calculate blade loads under wake conditions. Calculation of blade loads should make it possible to substantially increase the amount of energy that can be generated by new wind farms and to increase the safety and the lifespan of wind turbines. ■